# *Torso Stabilization Reduces the Metabolic Cost of Producing Cycling Power*

**John McDaniel[1,2], Andrew Subudhi[2], and James C. Martin[1]**

**Catalogue Data**
McDaniel, J.; Subudhi, A.; and Martin, J.C. (2005). Torso stabilization reduces the metabolic cost of producing cycling power. **Can. J. Appl. Physiol.** 30(4): 433-441. 

***Key words:*** *efficiency, economy, metabolism, static contraction, work*
***Mots-cles:*** *efficacité, économie, métabolisme, action statique, travail*

## Abstract/Résumé

*Many researchers have used cycling exercise to evaluate muscle metabolism. Inherent in such studies is an assumption that changes in whole-body respiration are due solely to respiration at the working muscle. Some researchers, however, have speculated that the metabolic cost of torso stabilization may contribute to the metabolic cost of cycling. Therefore, our primary purpose was to determine whether a torso stabilization device would reduce the metabolic cost of producing cycling power. Our secondary purpose was to determine the validity of the ergometer used in this study. Nine male cyclists cycled on a Velotron cycle ergometer at mechanical power outputs intended to elicit 50, 75, and 100% of their ventilatory threshold at 40, 60, and 80 rpm, with and without torso stabilization. Power was controlled by the Velotron in iso-power mode and measured with an SRM powermeter. We determined metabolic cost by indirect calorimetery and recorded power output. Torso stabilization significantly reduced metabolic cost of producing submaximal power (1%), and reduction tended to be greatest at the lower pedaling rates where pedaling force was greatest (1.6% at 40 rpm, 1.2% at 60 rpm, 0.2% at 80 rpm). Power, measured with the SRM powermeter, was strongly correlated with that specified to the Velotron ergometer control unit ($R^2$ > 0.99). We conclude that muscular contractions associated with torso stabiliza-*

[1]Dept. of Exercise and Sport Science, The University of Utah, 250 S. 1850 E. Room 241, Salt Lake City, UT 84112-0920 USA; [2]The Orthopedic Specialty Hospital, 5848 Fashion Blvd., Murray, UT 84107 (A. Subudhi is now in the Dept. of Biology at the University of Colorado, Colorado Springs).

*tion elicit significant metabolic costs, which tend to be greatest at low pedaling rates. Researchers who intend to make precise inferences regarding metabolism in the working muscles of the legs may wish to provide torso stabilization as a means of reducing variability, particularly when comparing metabolic data across a wide range of pedaling rates.*

*De nombreux chercheurs ont étudié le métabolisme musculaire au cours d'un effort sur ergocycle à partir du postulat que les variations de la respiration de tout l'organisme s'effectuent dans les muscles au travail. Des chercheurs, cependant, ont émis l'hypothèse que le coût énergétique de la stabilisation du torse contribuait au coût énergétique du pédalage sur l'ergocycle. Notre premier objectif est donc de vérifier si un dispositif de stabilisation du torse contribue à réduire le coût énergétique de la production de puissance sur un ergocycle. Notre deuxième objectif est d'établir la validité de l'ergocycle utilisé dans cette expérience. Neuf cyclistes masculins ont pédalé sur un ergocycle de marque Velotron à des intensités de 50, 75, et 100% du seuil ventilatoire à la cadence de 40, 60, et 80 rpm avec et sans stabilisateur du torse. La puissance produite était contrôlée par le Velotron en mode isopower et mesurée par un dynamomètre de marque SRM. Nous avons évalué le coût énergétique par calorimétrie indirecte, et nous avons enregistré la puissance produite. La stabilisation du torse diminue significativement le coût énergétique de la production de puissance sous-maximale (1%); la diminution étant moins importante avec l'augmentation de la cadence: 1,6% à 40 rpm; 1,2% à 60 rpm; et 0,2% à 80 rpm. La puissance mesurée par le dynamomètre de marque SRM est étroitement corrélée à la mesure donnée par l'unité de contrôle sur l'ergomètre ($R^2$ > 0,99). En conclusion, les contractions musculaires sollicitées pour la stabilisation du torse augmentent significativement le coût énergétique notamment si la cadence de pédalage est faible. Les chercheurs désireux de se prononcer précisément sur le métabolisme des muscles au travail dans les membres inférieurs pourraient vouloir stabiliser le torse pour réduire la variation du coût énergétique, surtout quand l'objectif est de comparer les coûts énergétiques en fonction de la cadence de pédalage.*

## Introduction

Many researchers have used indirect calorimetry to evaluate the metabolic cost of producing cycling power (e.g., Chavarren and Calbet, 1999; Coyle et al., 1992a; Horowitz et al., 1994; McDaniel et al., 2002; Sidossis et al., 1992). In such studies it is assumed that changes in whole-body respiration are due to respiration in the working muscle. Indeed, that assumption has been supported by Poole et al. (1992), who reported that changes in $\dot{V}O_2$ measured at the mouth paralleled changes in $\dot{V}O_2$ across the legs. Those findings suggest that either the cost of muscular contraction required for stabilizing the torso is insignificant or that it is a fixed value that does not change with intensity. Consistent with this, Lowe and Coast (1991) reported that the use of a tether belt to restrain the torso did not alter $\dot{V}O_2$ or gross mechanical efficiency during cycling. Despite these findings, several researchers have speculated that the metabolic cost of torso stabilization might contribute to the metabolic cost of producing cycling power (Coyle et al., 1992b; Hagberg et al., 1981; McDaniel et al., 2002; Takaishi et al., 1998), particularly when pedal forces are relatively high (e.g., low pedaling rates). Such speculation seems reasonable because static muscular contractions are known to elicit significant metabolic cost (Koerhuis et al., 2003).

During pilot work for a previous study, we perceived that high pedal force conditions at lower pedaling rates required substantial muscular effort in the arms and torso to remain in position on the ergometer saddle. We were concerned that metabolic cost associated with that muscular stabilization might influence our data (McDaniel et al., 2002) and bias our conclusions regarding metabolism in the working muscles. To address that concern, we fitted the ergometer with a torso stabilization device and instructed our subjects to relax their arms and torso during the experimental protocol.

At that time, however, we did not quantify the effects of the stabilization device on metabolic cost. Therefore, our purpose for conducting this study was to determine whether the metabolic cost of torso stabilization significantly contributed to the metabolic cost of producing cycling power across a wide range of experimental conditions. We hypothesized that a torso stabilization device would reduce the metabolic cost of producing cycling power, particularly at lower pedaling rates. The laboratory in which we conducted this study was equipped with a Velotron ergometer with an iso-power control mode. To our knowledge, that ergometer had not been independently validated. Therefore our secondary purpose in this study was to determine the validity of that ergometer by comparing power measured by the SRM with the power specified to the Velotron ergometer control unit.

## Methods

Participating in this study were 9 trained male cyclists with the following characteristics: age 30.8 ± 4.0 yrs; body mass 77.2 ± 5.3 kg; peak oxygen consumption ($\dot{V}O_2$ peak) 63.9 ± 4.4 ml·kg$^{-1}$·min$^{-1}$; $\dot{V}O_2$ at ventilatory threshold (VT) 47.7 ± 4.6 ml·kg$^{-1}$·min$^{-1}$; and power output that elicited VT 281 ± 39 watts. The protocol and data collection methods were thoroughly explained and the subjects signed a statement of informed consent. This study was reviewed and approved by the Intermountain Health Care Institutional Review Board.

The subjects reported to the laboratory for three separate sessions within a 2-week period. During the initial session, VT and peak oxygen consumption were determined. VT was determined using the ventilatory equivalence of the oxygen method described by Wasserman and McIlroy (1964). The cyclists began this incremental test by pedaling with a power output of 20 watts (W) for the first minute, and power was increased 25 W every minute thereafter until they reached volitional fatigue. Expired gas concentrations and ventilation were measured breath by breath and averaged over 20-sec periods (Parvo Medics, model True Max 2400, Sandy, UT) for calculation of oxygen and carbon dioxide consumption ($\dot{V}O_2$, $\dot{V}CO_2$) and respiratory exchange ratio (RER). $\dot{V}O_2$ peak was defined as the highest average $\dot{V}O_2$ measurement for any 20-sec period. Gas analyzers were calibrated prior to each collection period by using room air and a calibration gas of known concentration (4% $CO_2$, 16% $O_2$). Mechanical power output, heart rate, and pedaling rate were measured using a Schoberer Rad Messtechnik (SRM) power meter (Konigskamp, Germany) mounted on a Velotron electronic bicycle ergometer, Elite model (Seattle, WA). Power values measured and recorded by the SRM were compared with the power specified to the Velotron ergometer.

**Figure 1.** Torso stabilization device, made of steel tubing, padded with closed-cell foam, and mounted to the ergometer saddle.

Experimental data were recorded during two subsequent laboratory sessions. Subjects reported to the laboratory in a fasted state, at least 8 hrs postprandial, and performed the experimental protocol with or without the stabilization device (Figure 1), presented in a counterbalanced design. We instructed them to pedal in their customary manner when cycling without the stabilization device. When they cycled with the stabilization device, we instructed them to relax their arms and hands and let the stabilization device hold them stationary on the saddle. Pedaling rates of 40, 60, and 80 rpm were presented in random order. For each pedaling rate the subjects cycled for 15 min, during which the power was increased every 5 min (50, 75, and 100% of VT). Due to torque limitations of our ergometer, we were limited to 250 W during the 40-rpm stage. Therefore we used 50, 75, and 100% of 250 W for the 5 subjects whose VT exceeded this limitation. After completing all three intensities for the assigned pedaling rate, the subjects rested for 2 min before resuming exercise at the next assigned pedaling rate. The order of pedaling rates remained the same for both data collection periods for each subject.

Measurements from the 4th and 5th minutes of each stage, representing steady-state conditions, were used in data analysis. Metabolic cost was calculated by linear regression using the data and methods presented by Zuntz (1901) and was based on the thermal equivalent of $O_2$ for nonprotein respiratory equivalent: metabolic cost (kJ/min) = $4.187 \times (1.2341 \times \mathrm{RER} \times \dot{V}O_2 + 3.8124)$.

### STATISTICS

We used a Treatment × Pedaling rate × Intensity (2 × 3 × 3) completely repeated-measures analysis of variance (ANOVA, $\alpha = .05$) to determine the extent to which the stabilization device influenced the metabolic cost of producing cycling power. To correct for minor differences in power between the same pedaling rate and intensity conditions (2.4 ± 2.0 W), we performed linear regression on metabolic cost and mechanical power output data for each individual trial and used the regression equation ($R^2 = .998 \pm .001$) to calculate metabolic cost values at the mean of the two power outputs for each condition. This technique is roughly equivalent to a repeated-measures multiple analysis of covariance (MANCOVA), but with the additional refinement of using individual regression coefficients for each subject and each pedaling rate.

If the repeated-measures ANOVA indicated a significant main effect for support, we performed additional Support × Intensity repeated-measures ANOVAs to determine the main effects of support at each pedaling rate. To correct for the fact that these repeated analyses of simple main effects may be subject to inflated type I error, we performed a Bonferoni adjustment to set the $\alpha$ level at 0.0167 (0.05/3). We performed linear regression to determine the strength of the relationship of metabolic cost with mechanical power output. Finally, we compared the power that we specified for the Velotron ergometer with the power measured by the SRM with linear regression analysis.

## Results

The repeated-measures ANOVA indicated that the stabilization device significantly reduced the metabolic cost of producing cycling power by 1% ($p = 0.025$, power = 0.81). The repeated-measures ANOVA for each pedaling rate indicated that support significantly reduced metabolic cost for 40 rpm ($p = 0.012$) and 60 rpm ($p = 0.016$), but not for 80 rpm ($p = 0.67$). Metabolic cost increased with each increase in power output ($p < 0.001$; Table 1). Linear regression of data for all subjects and all conditions indicated that mechanical power output accounted for 96% of the variation in metabolic cost. Power specified to the Velotron ergometer control unit in the iso-power mode was strongly correlated with measured power as determined by the SRM (Measured power = 0.99 × Specified power; $R^2 > 0.99$).

## Discussion

Our main finding was that the torso stabilization device significantly reduced the metabolic cost of producing submaximal cycling power. Based on that finding, we conclude that muscular effort required to stabilize the torso during cycling elicits a small but significant increase in metabolic cost. On average, metabolic cost was reduced by 0.50 kJ/min, or approximately 1% when using the stabilization device. While a 1% decrease in metabolic cost may seem small, it is important to note that mechanical power output has been reported to account for 95% of the variation in metabolic cost of producing submaximal cycling power across a wide range of conditions (McDaniel et al., 2002). Indeed, mechanical power output accounted

**Table 1 Mean (± *SD*) Metabolic Cost for Each Condition (kJ·min$^{-1}$), With and Without Stabilization**

| | Metabolic Cost (kJ·min$^{-1}$) | | | | | |
|---|---|---|---|---|---|---|
| | 40 rpm | | 60 rpm | | 80 rpm | |
| | With | Without | With | Without | With | Without |
| Low | 35.2 ±1.2 | 35.9 ±1.3 | 35.7 ±1.1 | 36.2 ±1.0 | 37.6 ±1.1 | 37.4 ±1.2 |
| Medium | 49.9 ±1.5 | 50.6 ±1.5 | 49.4 ±1.6 | 50.0 ±1.5 | 50.8 ±1.6 | 50.9 ±1.5 |
| High | 66.5 ±67.4 | 67.4 ±1.8 | 64.6 ±1.8 | 65.2 ±1.7 | 65.3 ±1.9 | 65.7 ±2.0 |

*Note*: Stabilization significantly reduced metabolic cost by 1% ($p$ = 0.025) and tended ($p$ = 0.08 for Pedaling rate × Stabilization interaction) to exhibit a greater effect at lower pedaling rates: 1.6% at 40 rpm, 1.2% at 60 rpm, and 0.2% at 80 rpm.

for 96% of the variation in metabolic cost for the present study, suggesting that 1% of the overall cost represents a substantial portion of the remaining variance. Our findings suggest that researchers who hope to make precise inferences regarding metabolism in the legs may wish to consider providing their subjects with torso stabilization, particularly if they intend to compare data across a wide range of pedaling rates.

Our data indicated a main effect of stabilization on metabolic cost, and the follow-up ANOVAs indicated that support significantly reduced metabolic cost for 40 and 60 rpm but not for 80 rpm, supporting our hypothesis that stabilization would be particularly effective at lower pedaling rates where pedaling forces are greater. That is, the stabilization device provided the greatest reduction in metabolic cost at 40 rpm (1.6%) and 60 rpm (1.2%), compared with 80 rpm (0.2%), suggesting that the effect of torso stabilization increased with decreasing pedaling rate or, more important, with increasing pedal forces. Thus, even though our data indicated a significant main effect for the stabilization device, they do not necessarily contradict the findings of Lowe and Coast (1991) because their subjects cycled at a pedaling rate of 75 rpm. Even so, researchers who wish to detect small differences in metabolism in the working muscles of the legs may reduce variability in their data by providing torso stabilization for their subjects, particularly if they plan to compare data across a range of pedaling rates.

Interestingly, pedaling rate did not contribute significantly to metabolic cost in our present protocol. Previous researchers, including ourselves, have reported a curvilinear relationship between pedaling rates and the metabolic cost of producing mechanical power output (Clamann, 1993; Coast and Welch, 1985; Marsh and Martin, 1993; Takaishi et al., 1998), with a minimum cost occurring at approximately 60 rpm (Coast and Welch, 1985; Gaesser and Brooks, 1975; McDaniel et al., 2002; Takaishi et al., 1998). Our data support the curvilinear relationship between metabolic cost and pedaling rate because metabolic cost appears to be low-est for 60 rpm in all trials, with only slightly greater values at 40 and 80 rpm. We believe that the absence of a significant effect for pedaling rate simply reflects the fact that metabolic cost of pedaling at 40 and 80 rpm is only slightly different from the minimum that occurred at 60 rpm.

Our results may have important implications for competitive cycling performance. Oftentimes cycling events are won or lost during the climbing portions when pedaling rates may be quite low. Under those conditions, our results suggest that a stabilization device could reduce the metabolic cost of any specific power output by approximately 1%. Alternatively, a stabilization device would allow a cyclist to produce approximately 1% more power for a specific metabolic cost, such as maximal sustainable $\dot{V}O_2$. When climbing steep grades, speed tends to be nearly a linear function of power because the aerodynamic resistance is small (Jeukendrop and Martin, 2001). Consequently, a 1% increase in power would provide approximately a 1% increase in speed or a 1% decrease in time.

The actual performance benefit of using a torso stabilization device would be compromised in two ways. First, the mass of the torso stabilization device we used was 0.234 kg or approx. 0.3% of the mass of a 70-kg cyclist riding a 7-kg bicycle. Consequently, the actual performance benefit of the stabilization device during uphill cycling would be reduced by that amount to approx. 0.7% (1.3% at 40 rpm, 0.9% at 60 rpm, and –0.1% at 80 rpm). The stabilization device we used was made of tubular steel and covered with closed cell foam and vinyl tape. Thus, even though the performance advantage of our device would be compromised by weight, we believe such a device could be made much lighter if constructed of other materials such as aluminum, titanium, or carbon fiber composite. The benefits we predict for uphill cycling (up to 1.3%), therefore, represent the minimum benefit, which could likely be improved. Such a margin could easily mean the difference between winning or losing a major cycling race, and thus a torso stabilization device could be the deciding factor in the outcome of a race. A second limitation is that the use of a torso stabilizing device would eliminate the possibility of moving back on (or even off) the saddle as some riders do during descents. Riders who prefer to sit back on their saddle during descents may find this limitation unacceptable.

In this study we used the Velotron ergometer in iso-power mode to set the load for our subjects and collected data with an SRM power meter. The Velotron is a relatively new ergometer and, as yet, its reliability and validity have not been reported. Consequently, our secondary purpose was to evaluate the Velotron ergmometer. Our results indicated that power measured by the SRM was highly correlated with ($R^2 > 0.99$) but 1% greater than the power we input to the Velotron controller in iso-power mode. The SRM power meter has been reported to be accurate and reliable (Gardner at al, 2004; Martin et al., 1998). We carefully determined the slope of the SRM frequency-torque relationship by hanging known weights from various points on the sprocket. Additionally, we "zeroed" the unit prior to each trial and thus we are confident in the accuracy of our SRM power values. We believe this difference is due to the fact that the Veloton controls power at the flywheel, whereas the SRM measures power at the cranks. Consequently, power measured by the SRM must be greater than the power at the flywheel, due to friction loss in the drive chain. The slope of the regression line we found in this study represents a high but reasonable value for chain drive efficiency, i.e., 99%. Thus the Velotron appears to be a valid and reliable research ergometer.

In summary, we interpret these data to indicate that the muscular effort required to stabilize the torso during cycling elicits a small but significant increase in metabolic cost. This cost tended to be greatest at lower pedaling rates when pedal forces were largest. Use of a torso stabilization device may help researchers detect small differences in metabolism in the work-producing muscles of the legs, particularly at low pedaling rates. Competitive cyclists may obtain a slight advantage under certain conditions by using a stabilization device, provided that the relevant governing body allows it. Finally, power measured by the SRM was 1% greater than that specified to the Veloton ergometer controller, which may be due to the efficiency of the chain drive system.

## References


Chavarren, J., and Calbet, J.A. (1999). Cycling efficiency and pedalling frequency in road cyclists. **Eur. J. Appl. Physiol. Occup. Physiol.** 80: 555-563.

Clamann, H.P. (1993). Motor unit recruitment and the gradation of muscle force. **Phys. Ther.** 73: 830-843.

Coast, J.R., and Welch, H.G. (1985). Linear increase in optimal pedal rate with increased power output in cycle ergometry. **Eur. J. Appl. Physiol. Occup. Physiol.** 53: 339-342.

Coyle, E.F., Sidossis, L.S., Horowitz, J.F., and Beltz, J.D. (1992a). Cycling efficiency is related to the percentage of type I muscle fibers. **Med. Sci. Sports Exerc.** 24: 782-788.

Coyle, E.F., Sidossis, L.S., Horowitz, J.F., and Beltz, J.D. (1992b). Cycling efficiency is related to the percentage of type I muscle fibers. **Med. Sci. Sports Exerc.** 24: 782-788.

Gaesser, G.A., and Brooks, G.A. (1975). Muscular efficiency during steady-rate exercise: Effects of speed and work rate. **J. Appl. Physiol.** 38: 1132-1139.

Gardner, A.S., Stephens, S., Martin, D.T., Lawton, E., Lee, H., and Jenkins, D. (2004). Accuracy of SRM and power tap power monitoring systems for bicycling. **Med. Sci. Sports Exerc.** 36: 1252-1258.

Hagberg, J.M., Mullin, J.P., Giese, M.D., and Spitznagel, E. (1981). Effect of pedaling rate on submaximal exercise responses of competitive cyclists. **J. Appl. Physiol.** 51: 447-451.

Horowitz, J.F., Sidossis, L.S., and Coyle, E.F. (1994). High efficiency of type I muscle fibers improves performance. **Int. J. Sports Med.** 15: 152-157.

Jeukendrup, A.E., and Martin, J. (2001). Improving cycling performance: How should we spend our time and money? **Sports Med.** 31: 559-569.

Koerhuis, C.L., van der Heide, F.M., and Hof, A.L. (2003). Energy consumption in static muscle contraction. **Eur. J. Appl. Physiol.** 88: 588-592.

Lowe, R.C., and Coast, J.R. (1991). The physiological effects of a tether belt system. Do tether belts and other restraining systems improve pedaling efficiency? **Cycling Science** 3: 27-30.

Marsh, A.P., and Martin, P.E. (1993). The association between cycling experience and preferred and most economical cadences. **Med. Sci. Sports Exerc.** 25: 1269-1274.

Martin, J.C., Milliken, D.L., Cobb, J.E., McFadden, K.L., and Coggan, A.R. (1998). Validation of a mathematical model for road cycling power. **J. Appl. Biomech.** 14: 276-291.

McDaniel, J., Durstine, J.L., Hand, G.A., and Martin, J.C. (2002). Determinants of metabolic cost during submaximal cycling. **J. Appl. Physiol.** 93: 823-828.

Poole, D.C., Gaesser, G.A., Hogan, M.C., Knight, D.R., and Wagner, P.D. (1992). Pulmonary and leg $VO_2$ during submaximal exercise: Implications for muscular efficiency. **J. Appl. Physiol.** 72: 805-810.

Sidossis, L.S., Horowitz, J.F., and Coyle, E.F. (1992). Load and velocity of contraction influence gross and delta mechanical efficiency. **Int. J. Sports Med.** 13: 407-411.

Takaishi, T., Yamamoto, T., Ono, T., Ito, T., and Moritani, T. (1998). Neuromuscular, metabolic, and kinetic adaptations for skilled pedaling performance in cyclists. **Med. Sci. Sports Exerc.** 30: 442-449.

Wasserman, K., and McIlroy, M.B. (1964). Detecting the threshold of anaerobic metabolism in cardiac patients during exercise. **Am. J. Cardiol.** 14: 844-852.

Zuntz, N. (1901). Über die Bedeutung der verschiedene Nahrstoffe als Erzeuber der Muskelkraft [On the relevance of various nutrients as the generator of muscle force]. **Pflugers Arch.** 83: 557-571.

*Received September 10, 2004; accepted in final form November 16, 2004.*